Transmission Failure Rate for Computed Tomography Examinations in a Filmless Imaging Department

Bruce Reiner, Eliot Siegel, Peter Kuzmak, and Steve Severance

The purpose of the study was to determine the frequency and causes of unsuccessful computed tomography (CT) transmissions in a filmless imaging department and to determine the added efficiency gains provided by the sequential addition of modality worklist software and a major network upgrade. Prospective data on CT transmission error rates were recorded over an 18-month period. During the study interval, modality worklist functionality was added, followed by a network upgrade. Failed transmissions were categorized as to the source of the error (human v technical), and the specific problem encountered. Prior to the introduction of modality worklist software, the initial CT transmission failure rate was 7.6%, which was primarily the result of human error (69%), in the form of data entry error. Upon the introduction of modality worklist software, the transmission failure rate decreased to 3.5%, with human error accounting for only 16% of all failed transmissions. The subsequent addition of a network upgrade from shared Ethernet to switched Ethernet further reduced the transmission failure rate to 2.0%, which was believed to be the result of a reduction in the number of network collisions. Other sources of failed transmission occur at the levels of the CT scanner (network interface card), picture archiving and communication system (PACS)/hospital information system (HIS) interface, and modality gateway. When planning the transmission from film-based to filmless operation, one should consider various hardware, software, and infrastructural requirements to ensure successful PACS implementation. Software upgrades, in the form of modality worklist software, serve to improve technologist productivity by minimizing data entry error. Infrastructural changes, in the form of network upgrading, ensure proper dissemination of electronic data with decreased frequency of network collisions. Collectively, these improvements lead to enhanced transmission of digital images, resulting in productivity gains within the filmless CT department.

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THE DEVELOPMENT of the Digital Imaging and Communications in Medicine (DICOM) standard for medical images came out of the collaboration between the American College of Radiology (ACR) and the National Electronic Manufacturer's Association (NEMA). This has been accepted by the majority of manufacturers involved in the development of medical imaging devices and allows for the transfer of medical images between imaging modalities and picture archiving and communications systems (PACS)

workstations. One of the drawbacks to date in the typical hospital network is that medical imaging devices and the data they produce are typically isolated from the various information systems within the hospital (Fig 1). This deficit is due in part to the lack of a defined standard for data communication between imaging systems and hospital/radiology information systems (HIS/RIS). This has served as the impetus for the collaborative initiative between the Radiological Society of North America (RSNA) and Healthcare Information and Management Systems Society (HIMMS), referred to as Integrating the Healthcare Enterprise (IHE).

Most medical imaging modalities, such as computed tomography (CT), are capable of using one or more DICOM service classes for transferring information between imaging equipment and PACS workstations. However, the process of integrating medical images with other patient data to create an electronic medical record (EMR) is seldom practiced. The DICOM standard has recently been established to solve this difficulty in integrating data, with the adoption of the standard for Basic Modality Worklist Management. This standard offers the ability to synchronize medical imaging data with that of other patient data, including demographic, financial, laboratory/pathology reports, etc.

The purpose of this study was to determine the relative frequency of unsuccessful transfers or mislabeled images sent to PACS from CT scanners, in a fully functioning filmless imaging department. By better understanding the frequency and causative factors associated with faulty CT transmission, we hope to develop more effective strategies in optimizing image transmission from all modalities, in a filmless environment.

From the Baltimore Veterans Affairs Medical Center; American Radiology Services, Baltimore; University of Maryland School of Medicine, Baltimore, MD; and Department of Veterans Affairs, Technology Service, Silver Spring, MD.

Address reprint requests to Bruce I. Reiner, MD, University of Maryland/American Radiology Services, 21779 Cove Lane, Leonardtown, MD 20650. E-mail: breiner@mail.ameritel.net.

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MATERIALS AND METHODS

Prospective data on CT transmission failure rates were recorded over an 18-month study period. Three CT technologists, each with extensive CT and PACS experience, recorded data, which documented CT transmission failures. The cumulative CT and PACS experience for these technologists were 36 and 12 years, respectively. Data recorded included the CT examination type, date and time of examination, technologist performing the study, success or failure of CT transmission to the PACS, and the source of transmission failure, when applicable. Estimates were also recorded quantifying the time required to rectify the transmission failure, to allow for radiologist interpretation of the study.

CT scanning was performed on one of two helical CT scanners (PQ-5000 and PQ-6000, Picker International, Highland Heights, OH). While both CT units were capable of transmitting DICOM image objects, the commercial PACS used for the study (GE Medical Systems, Milwaukee, WI) was not initially able to communicate directly via DICOM. This communication was accomplished with implementation of modality gateways which used the DeJarnette DOS-based ImageShare 910 (DeJarnette Research Systems, Towson, MD). These gateways served to translate the DICOM image objects generated by the CT scanners into PACSNET objects that were sent to the PACS modality interface unit (MIU).

RESULTS

Prior to implementation of modality workload software, the CT transmission failure rate was 7.6%, with 48 unsuccessful transmissions out of 634 cases (Table 1). When categorizing the source of these transmission failures, more than two thirds (69%), were found to be the result of human error. These human errors were almost exclusively the result of improper data entry, in the form of incorrect spelling or error in identification number entry.

After incorporation of modality workload software, a significant decrease in CT transmission failures was observed, from an initial rate of 7.6% to 3.5%, representing a net decrease of 54%. The

Table 1. CT Transmission Failure Rate With/Without Modality Worklist

	Overall Failure Rate	Human Failure Rate	Technical Failure Rate
Without modality worklist (n = 634)	7.6%	5.2%	2.4%
With modality worklist (n = 1,025)	3.5%	0.7%	2.8%
With modality worklist and network upgrade (n = 1,040)	2.0%	0.8%	1.2%

rate of failed transmission due to human error decreased from 5.2% to 0.7% subsequent to implementation of modality workload.

A further improvement in CT transmission failure rate was observed after upgrading the network from shared Ethernet to switched Ethernet. While this did not have any significant effect on human error, it did produce a significant decrease in overall transmission errors, from 2.8% to 1.2%. This was believed to be the result of decreased number of network collisions with the upgraded network.

The average time delay in CT interpretation caused by failed CT transmission was approximately 20 minutes. In the case of equipment malfunction, this often required retransmission of the entire image data file. This file could be as large as 150 images in a complicated oncology patient, with imaging of multiple anatomic regions. Human errors, on the other hand, were more quickly corrected by the technologists, by re-entering the examination and patient profile data. In total, this required an additional 3 to 5 minutes of technologist time.

In all cases of failed transmissions, an additional delay of 10 to 15 minutes was required to identify the failed transmission. This was listed as an "unspecified exam" in the workstation workload folder. If not promptly identified and corrected, the examination and accompanying report would not be correctly archived in the patient's electronic image folder and therefore not accessible to referring clinicians or radiologists for future review. This in turn often caused the examination to be unnecessarily repeated.

Using the annual estimated CT examination

Fig 1. Relationship between imaging modalities and information systems.

volume at our institution of 8,000 exams, the estimated number of failed CT transmissions annually would be 608 at a failure rate of 7.6% (prior to modality worklist). At a conservatively estimated time delay of 20 minutes per examination, this equates to 203 hours or 25 working days of "lost" technologist/radiologist time. Upon implementation of modality worklist and the switched network, the number of annual CT transmission failures decreases to 160 (2%), equating to approximately 53 hours and 7 working days of "lost" time. These observations underscore the importance of software upgrades in the overall effect of PACS on technologist and radiologist productivity.

DISCUSSION

Previous work¹⁻⁴ has demonstrated enhanced technologist and radiologist productivity in a filmless imaging department. CT technologists have been shown to enhance productivity by more than 50% operating in a filmless environment, largely due to the elimination of time consuming steps related to film processing. Radiologists have been shown to increase productivity by 30% to 50%, largely due to the enhancements in image display and archival using PACS.

In a filmless environment, one of the major challenges is for accurate and rapid image identification, regardless of the imaging modality. In order to successfully transmit digital images, the technologist must first manually enter the examination profile consisting of the patient's name and identification number, exam identification number (obtained from the HIS/RIS), exam type, date and time. If incorrect, the examination will be incorrectly filed in the electronic database in one of four possible ways: (1) creation of a new electronic folder under a "new" patient name or identification number; (2) placement of images into another patient's folder; (3) placement of images into a wrong study folder, for the correct patient; or (4) PACS not accepting the images.

These errors can be largely alleviated by creation of an HIS/RIS to modality interface, using a DICOM modality worklist. This worklist can result in reduced technologist labor, increased accuracy of linking patient demographic data and scan information, and ultimately the integration of the examination results (images and reports) with the EMR. This interface is a prerequisite to proper synchronization of medical images and other pa-

tient information. An additional benefit of the DICOM modality worklist functionality is the ability to initiate one of two search modes for retrieving patient data from the HIS/RIS, automatic and manual searches. The automatic search requests CT examinations from the HIS/RIS prior to the scheduled exam time and stores the data locally in the modality worklist database. When a patient arrives for the scheduled CT, the technologist can access the appropriate clinical information. The manual search is initiated by the technologist as the result of a specific operator request. Search keys provided include the patient's name or identification number, exam identification number, and the date range. The operator can use any combination of search keys for the manual search to define the scope of the search.

In the absence of this modality worklist software, other approaches have been used. One is use of a bar-code reader, where the CT "uploads" patient and examination information from the paper requisition. However, this is limited by the fact that most modalities do not support bar-code printouts and bar-codes are often difficult to read. An additional drawback in a PACS environment is that this strategy requires paper forms, which undermines the paradigm shift to a filmless, paperless imaging environment.

The approach most commonly used in the absence of modality worklist software is patient and examination profiling. Information is manually typed into the CT scanner by the technologist, identifying the patient and specific exam. As previously stated, this has the potential to result in lost images and reduced technologist productivity. Improper "profiling" also delays radiologist interpretation, and requires the technologist to "merge" the improperly created new image folder into the proper exam folder, prior to radiologist interpretation. If this is not done, clinicians cannot access the examination, rendering it unavailable for future review and comparison.

CONCLUSION

To date, the experience with filmless imaging at Baltimore Veteran's Affairs Medical Center has been positive, with lower CT transmission failure rates than previously reported. Human error has been found to be almost exclusively associated with data entry error, which can be effectively

eliminated by incorporation of modality worklist software. Equipment-related transmission failures are largely due to interface problems between the CT scanner, PACS, and HIS/RIS. Additional col-

laboration is required between the respective vendors to reduce these transmission errors to more acceptable levels, in order to enhance productivity in a filmless CT department.

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